5

MEASUREMENT OF METAL POLISH QUALITY

10 INVENTORS
Paul H. Shelley
Bruce R. Davis

FIELD OF THE INVENTION

This invention relates generally to measurement, and, more specifically, to
15 measurement of metal surfaces.

BACKGROUND OF THE INVENTION

Bare metal surfaces are utilized in a variety of applications, such as the outer surfaces or skins of vehicles, including aircraft. Bare metal surfaces are polished for aesthetic and drag reduction purposes. Ascertaining the degree and quality of a metal polish has typically
20 been performed by visual inspection, with the inspector relying on his or her experience and on reference samples containing various surface polishes. Thus, current visual polish inspections involve a substantial degree of subjectivity.

Panels manufactured and polished at different times, or by different processes or entities, may have different polish qualities and thus, look different from each other.
25 Typically, clean polished metal surfaces present a uniform color when viewed from a position perpendicular to the surface, but often show variations in color or reflectivity when viewed from an angle if the degree of polish differs. In equipment where uniform polish is desired, such as with vehicles or fleets, uniformity of polish quality is important. By way of example, aircraft constructed with aluminum skin sections of differing degrees of polish can
30 present an undesirable checkerboard or segmented look. In equipment manufactured in different segments, obtaining a uniform degree of polish across multiple segments may also

- 1 -

be important. However, as previously stated, current visual inspection of polish for quality control and panel matching involves a substantial degree of subjective judgment by the visual inspector.

Therefore, there currently exists an unmet need in the art for a non-destructive, quantitative, and objective determination of quality of polishing on metal substrates.

SUMMARY OF THE INVENTION

The present invention provides a non-destructive method for efficiently and objectively determining the degree of polish on a metallic substrate or sample. The present invention may be used to measure the degree of polish over a wide area, and to quantitatively provide measurements of the degree of polish. Advantageously, the present invention provides an objective, quantitative method for measuring the degree of polish on metal substrates.

According to one embodiment of the present invention, a value of infrared energy reflected from a metallic substrate with a polished surface is determined. The value of the infrared energy reflected, or conversely absorbed, is correlated to a degree of polish. According to one aspect of the present invention, one method utilizes an infrared spectrometer to determine infrared absorbance of a polished metallic substrate. An infrared beam is reflected off the metallic substrate. The infrared energy of the reflected beam is then compared with the pre-determined value of infrared energy reflected off a reference polished surface to determine the degree of polish.

According to another aspect of the present invention, a ratio of infrared energy absorbance of at least two wavelengths of a polished metallic substrate is compared with a reference polished surface.

BRIEF DESCRIPTION OF THE DRAWINGS

The preferred and alternative embodiments of the present invention are described in detail below with reference to the following drawings.

FIGURE 1 is a cross-section drawing of a polish measurement device in accordance with the present invention;

FIGURE 2 is a graph of infrared absorbance of aluminum alloy polished surfaces;

FIGURE 3 is a flow chart of an exemplary testing method of the present invention;

FIGURE 4 is a flow chart of a further exemplary testing method of the present invention; and

FIGURE 5 is a flow chart of an exemplary polish matching method of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

By way of overview, a non-destructive method is provided for determining a degree of polish of a metallic substrate. A value I_s of infrared energy reflected by a polish surface on a metallic substrate is determined. The value I_s of infrared energy reflected by the polish surface correlates to a degree of polish.

The degree or quality of polish corresponds to surface smoothness at a very fine scale of the metallic substrate. Higher quality polished surfaces are smoother, and reflect light more uniformly and with less scatter than lower quality polishes. Increasing degrees or qualities of polish are suitably obtained by increasing polishing time and by the use of progressively finer grained polishing compounds.

FIGURE 1 is a cross-section drawing of an exemplary testing device 30 used to determine the quality of polish on a metallic substrate according to one presently preferred embodiment of the invention. An infrared transmission beam 15 is transmitted by an infrared source 32. The beam 15 is reflected off a sample surface 10, and the reflected beam 16 is detected by an infrared detector 34. It will be appreciated that the infrared source 32 and the infrared detector 34 suitably may include an infrared spectrometer. The infrared source 32 suitably may include a multi-frequency infrared source 32, and the infrared detector 34 may include a single or multiple frequency detector. In the embodiment shown in FIGURE 1, the infrared detector 34 detects infrared energy at two wavenumbers. The infrared levels received by the infrared detector 34 are output as an electrical signal to a processor or display 40 through a common conductor 37, a low frequency output conductor 35 and a high frequency output conductor 39.

The detector 34 may suitably detect infrared energy including the utilization of one or more narrow pass filters (not shown) and a broadband infrared source 32. In another presently preferred embodiment, the infrared source 32 and infrared detector 34 are suitably included in a portable infrared spectrometer such as a SOC-400 FTIR, manufactured by Surface Optics Corporation. In an alternate embodiment, an imaging infrared spectrometer may be utilized.

It will be appreciated that in this exemplary testing device 30, the infrared beam 15 has an angle of incidence α to the surface 10 of approximately 15 degrees. The reflected infrared beam 15 has an angle of reflection β of 15 degrees from the surface 10. It will be appreciated that the angle of incidence α may vary with materials being measured, so long as consistent angles of incidence α and reflectance β are utilized for comparing different samples.

25315

PATENT TRADEMARK OFFICE

The testing device 30 suitably measures a grazing infrared reflectivity of the surface 10. It will be appreciated that oblique reflection off the surface 10 is more sensitive to surface texture than acute reflection.

The testing device 30 includes a housing 36 holding the infrared source 32 and infrared detector 34. The housing 36 rests on feet 38 that hold the infrared source 32 and infrared detector 34 at a predetermined distance and position relative to the surface 10. The mobility of the device 30 permits additional measurements of adjoining areas and other samples with comparable results. It will be appreciated that the testing device 30 shown in FIGURE 1 suitably measures grazing angle specular reflectance at an angle greater than 70 degrees from normal to the surface 10.

The device 30 of FIGURE 1 may be utilized to non-destructively determine the degree of polish on the surface 10. Initially, a base reference value I_0 of infrared energy reflected by a reference polished metallic sample (not shown) is determined. The device 30 is then used to transmit the infrared beam 15 to the surface 10 to be tested. A comparison is made between the reflected infrared energy of the sample and the reflected infrared energy reference to calculate a quality of polish.

FIGURE 2 includes six infrared grazing angle absorbance spectra over a range of wavenumbers (cm-1) from six variously polished metallic surfaces (not shown). As is known, wavenumbers, expressed as wavelengths per centimeter (cm-1), are the inverse of wavelengths λ, expressed in centimeters. Absorbance spectra A through F show absorbance versus wavenumbers from approximately 4,000 cm-1 to approximately 400 cm-1. Absorbance in this instance is calculated as the log 10 of the quantity 1 divided by reflectivity (that is, log 10 (1/R)), and is graphed on a range of approximately -0.01 to 0.08.

Spectrum A is the absorbance spectrum of an unpolished area of an aluminum alloy surface. Spectrum A has an absorbance of approximately 0.85 at 4,000 wavenumbers and declines roughly in a straight line to 0.01 at approximately 900 wavenumbers, and then declines with variation to around 0.005 between 900 wavenumbers and 500 wavenumbers.

Spectrum B is the absorbance spectrum of a low quality polish of the same aluminum alloy surface as used for Spectrum A. Spectrum B declines in a roughly straight line from an absorbance of approximately 0.65 at 4,000 wavenumbers to approximately 0.01 at 900 wavenumbers, and then declines with variation to approximately 0.005 at 500 wavenumbers.

Spectrum C is the absorbance spectrum of a low-medium quality polish on the same aluminum alloy surface mentioned above. Spectrum C declines in a roughly straight line from an absorbance of approximately 0.53 at 4,000 wavenumbers to approximately 0.01 at

25315
PATENT TRADEMARK OFFICE

BLACK LOWE & GRAHAM PLLC

816 Second Avenue
Seattle, Washington 98104
206.381.3300 • F: 206.381.3301

900 wavenumbers, and then declines with variation to approximately 0.005 at 500 wavenumbers.

Spectrum D is the absorbance spectrum of a good quality polish on the same aluminum alloy surface sample. Spectrum D has an absorbance of approximately .03 at 4,000 wavenumbers, declining in a roughly straight line to 0.01 at 900 wavenumbers, then with variation to approximately 0.005 at 500 wavenumbers.

Spectrum E is the absorbance spectrum of a very good quality polish on the same aluminum alloy surface. Spectrum E has an absorbance of approximately 0.025 at 4,000 wavenumbers declining roughly in a straight line to 0.01 at 900 wavenumbers, and then with variation to approximately 0.005 at 500 wavenumbers.

Spectrum F is the absorbance spectrum of a polished reference sample from Alcoa Company, polished to an extremely high degree. Spectrum F has an absorbance of approximately 0.018 at 4,000 wavenumbers and declines in roughly a straight line with some variability between 1,750 and 900 wavenumbers to approximately 0.01 at 900 wavenumbers, and then with variation to approximately 0.005 at 500 wavenumbers.

As shown in FIGURE 2, it will be appreciated that at a wavenumber of approximately 3,900, corresponding to a wavelength of 2.53 μm, progressively higher degrees of polish exhibit decreased absorbance. At the same time, all six spectra have approximately the same absorbance at 900 wavenumbers, or a wavelength of approximately 11.11 μm. Thus, the degree of polish may suitably be correlated to absorbance at wavenumbers greater than 900, with greater differentiation exhibited at wavenumbers greater than 2,000.

It will also be appreciated that a degree of metal polish may be suitably correlated to absorbance at a single wavenumber, such as 3,900 wavenumbers. In an alternative embodiment, a degree of metal polish may suitably be correlated to a ratio between absorbance at a higher wavenumber with a lower wavenumber, utilizing absorbance at the lower wavenumber to suitably equalize, or provide a reference between the spectra of different samples. For example, aluminum alloy substrates typically exhibit absorbance of approximately .01 at 900 wavenumbers. However, there can be variability between samples arising from a combination of factors unrelated to the degree of surface polish such as contamination, alloy differences, and residual polishing compound. Measurement accuracy may be increased by deriving a ratio for each sample between absorbance at a higher wavenumber, suitably near 3,900 wavenumbers, to absorbance at a lower wavenumber, suitably around 900 wavenumbers. At 900 wavenumbers, variations of absorbance, where they occur, tend to arise from factors other than polish. Dividing by the absorbance at 900 wavenumbers decreases the influence of these factors on the polish measurement. In an

alternate embodiment, absorbance at 900 wavenumbers may be subtracted from absorbance at the higher wavenumber, to produce a single equalized absorbance value. This alternative embodiment also decreases the influence of factors other than polish quality. Subtracting the absorbances may be preferred when absorbance at 900 wavenumbers is near or equal to zero, thus avoiding dividing by zero where a ratio of the absorbances is calculated.

In the example shown, the quality of polish for Spectrum A may be defined as a ratio of 8.5. This is the ratio between absorbance of 0.085 at 3,900 wavenumbers to 0.01 at 900 wavenumbers, indicating a poor polished quality or an unpolished area. A surface such as Spectrum E, with a very good high quality polish, has a ratio of 2.5 reflecting an absorbance of 0.025 at 3,900 wavenumbers divided by 0.01 at 900 wavenumbers. It will be appreciated that FIGURE 2 is a graph of absorbance of the Spectra A-F. With absorbance being the converse of reflectivity, a comparison of reflectivity may suitably be utilized to generate results equivalent to plotting absorbance.

It will be appreciated that absorbance at wavenumbers between 2,000 and 4,000 corresponds to polish quality due to reflectance being affected by the texture of the reflected surface, in relation to the wavelength of the infrared light being reflected off that surface. Unpolished surfaces, which are rougher surfaces at a fine scale, have greater absorbance than smoother polished surfaces, especially at wavenumbers greater than 2,000.

Infrared reflectivity for bare metal at grazing angles is dependent on surface smoothness, or degree of polish, more so than the type of metal sampled. Thus, the methods of the present invention are applicable to reflectivity, and hence the degree of polish for a plurality of metals. It will be appreciated that grazing reflectivity measurement at infrared frequencies is suitably advantageous to such measurements at visual frequencies because measurements at infrared frequencies are more sensitive to surface texture at the scale present in polished metals.
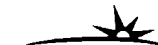
Referring to FIGURE 3, one presently preferred embodiment of the present invention is implemented through a polish measurement method 101. At a block 100, infrared reflectance I_1 of the sample is measured at a first frequency. At a block 110, infrared reflectance I_2 of the same sample at a second frequency is measured. At a block 120, a ratio is derived between I_1 and I_2. At a block 130 the ratio is compared to a reference to determine polish quality. The comparison, by way of example but not limitation, can be done manually by comparison to written reference data, or by computer.

As described above in FIGURES 2 and 3, it will be appreciated that for metal substrates, the infrared absorbance I_1 suitably may be obtained by measuring reflectivity at a wavenumber greater than 2,000, and suitably around 3,900. The infrared absorbance at the

- 6 -

BOEI-1-1194AP

25315

PATENT TRADEMARK OFFICE

BLACK LOWE & GRAHAM PLLC

816 Second Avenue
Seattle, Washington 98104
206.381.3300 • F: 206.381.3301

second frequency I_2 may suitably be determined at a wavenumber of around 900. In reference to FIGURE 2, the method 101 of FIGURE 3 produces repeatable quantitative references of polish quality. For example, an unpolished aluminum alloy surface has a ratio of approximately 8.5. A very good quality polish surface has a ratio of approximately 2.5.

5 These ratios compare to a high quality reference with a ratio of 1.8, such as a polished aluminum alloy reference sample from Alcoa as shown in Spectrum F of FIGURE 2. The method 101 of FIGURE 3 thus, derives a quantitative degree of polish measurement which may be utilized for measuring the polish quality of individual samples, equipment segments, or which may be utilized during manufacture to equalize polish for adjoining or multiple

10 sections where the degree of polish is desired to be standardized.

Referring to FIGURE 4, it will be appreciated that, for samples or surfaces not significantly affected by factors other than polish quality, a measurement of infrared reflectivity at one wavenumber may be utilized to determine a degree of polish using a polish measurement method 201.

15 At a block 200, infrared absorbance I_s of the sample is derived at a single wavenumber. At a block 210, the infrared reflectivity I_s is compared to a reference surface to determine a degree of polish. Referring again to FIGURE 2, the various spectra A-E of the same aluminum sample with progressively better polish quality in this sample set does not reflect variability from each other at lower wavenumbers. Thus, it has been found that

20 absorbance at a single wavenumber greater than 2,000, and suitably around 3,900 for metals, may derive an accurate degree of polish. The method 201 does not include calculating a ratio between absorbance at a first wavenumber and absorbance at a second wavenumber. In FIGURE 2, absorbance of the unpolished aluminum alloy surface at 3,900 wavenumbers of .085 (Spectrum A) may be directly compared with the absorbance of a very good quality

25 polished aluminum surface at .025 (Spectrum E), and a highly polished reference sample from Alcoa (Spectrum F) with an absorbance of .018. It has been determined that equivalent levels of absorbance of polished surfaces at wavenumbers greater than 2,000, and suitably at around 3,900, correspond visually similar and equivalent polish quality. The method 201 thus, may be used to non-destructively derive a quantitative measurement of polish quality.

30 It will be appreciated that a method of the present invention may be utilized to prepare uniformly polished metallic surfaces. As noted above, in an application such as aircraft involving multiple metallic panels or adjoining metallic panels, differences in polish can result in a patchworked visual appearance or different quantities of drag. In other applications where multiple independent items are desired to have the same look, whether

35 manufactured by different parties or treated differently during their manufacturing processes,

25315

PATENT TRADEMARK OFFICE

uniformity may be desired. For example, in architectural metals, a uniform look is often specified for metals being used in a building. Utilizing a method 301 of FIGURE 5, standard polished surfaces may suitably be obtained.

At a block 300, the absorbance or absorbance ratio of a first sample is obtained using a method described above in connection with FIGURES 3 or 4. At a block 310, the infrared absorption of a second sample is obtained using the same method as for the first sample. At a block 320 the absorbances of the two separate samples are compared. If the absorbances, and hence the degree of polish of the samples, are about equal, the method is completed. Otherwise, the polish of one or the other or both of the samples are adjusted or equalized at a block 330.

Thus, the method 301 provides equalization of polish quality of different samples. Where the polish quality of both samples is adjusted as needed, the polish quality of both samples may be standardized to yet a third sample or other reference. The method 301 of the present invention may be used to yield uniform adjoining metallic sections on equipment and uniformity among separate surfaces. It will be appreciated that for fleet vehicles, including aircraft, a common visual appearance of metallic equipment when viewed simultaneously from a variety of angles may be desired. Similarly, architectural metals used in building surfaces and trim may advantageously be equally polished. Utilizing the method 301 of FIGURE 5, by way of example and not limitation, a fleet of aircraft using bare metal sections may be uniformly polished individually and across the members of the fleet. The result is a uniform appearance even when the equipment is viewed from different angles. Because the human eye picks up subtle variations in polish quality, especially at grazing angles, the method of the present invention advantageously provides a way for standardizing the visual appearance of metallic surfaces.

While the preferred embodiment of the invention has been illustrated and described, as noted above, many changes can be made without departing from the spirit and scope of the invention. Accordingly, the scope of the invention is not limited by the disclosure of the preferred embodiment. Instead the invention should be determined entirely by reference to the claims that follow.